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(54) **LIGHT EMITTING DEVICE**

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H01L 33/12 (2010.01)
H01L 33/32 (2010.01)

(52) **U.S. Cl.**

CPC ***H01L 33/04*** (2013.01); ***H01L 33/12*** (2013.01); *H01L 33/32* (2013.01)

(58) **Field of Classification Search**

CPC H01L 33/12; H01L 33/04; H01L 33/06
See application file for complete search history.

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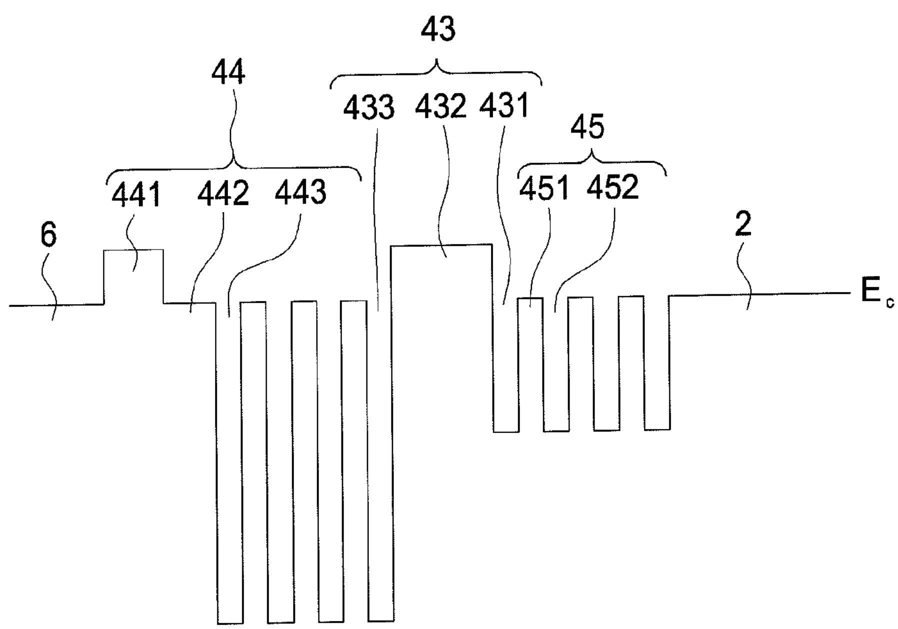
(57) **ABSTRACT**

A light-emitting device comprises a first type semiconductor layer, a multi-quantum well structure on the first type semiconductor layer, and a second type semiconductor layer on the multi-quantum well structure, wherein the multi-quantum well structure comprises a first portion near the first type semiconductor layer, a second portion near the second type semiconductor layer, and a strain releasing layer between the first portion and the second portion and comprising a first layer including Indium, a second layer including Aluminum on the first layer, and a third layer including Indium on the second layer, wherein the Indium concentration of the third layer is higher than that of the first layer.

13 Claims, 3 Drawing Sheets



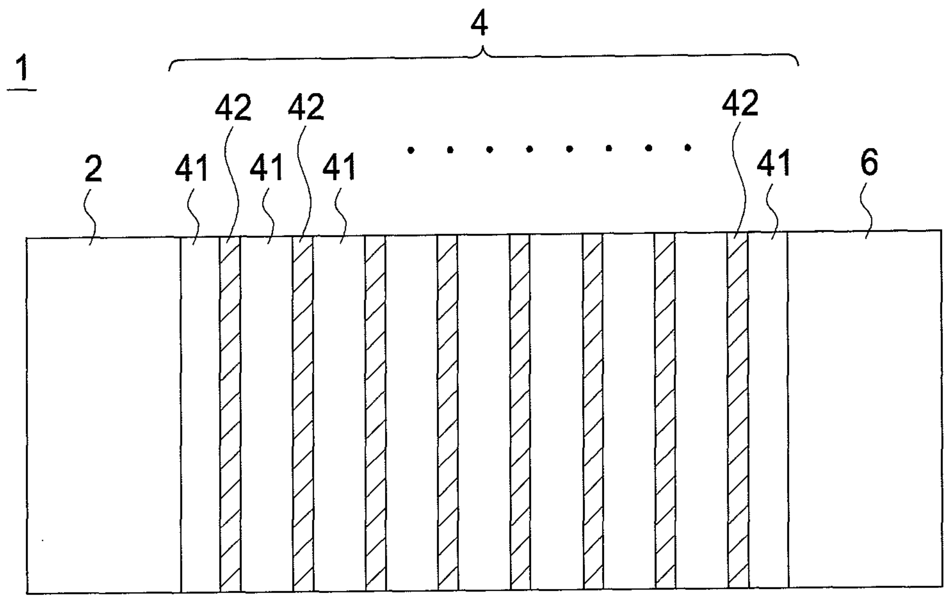


FIG.1
(Prior Art)

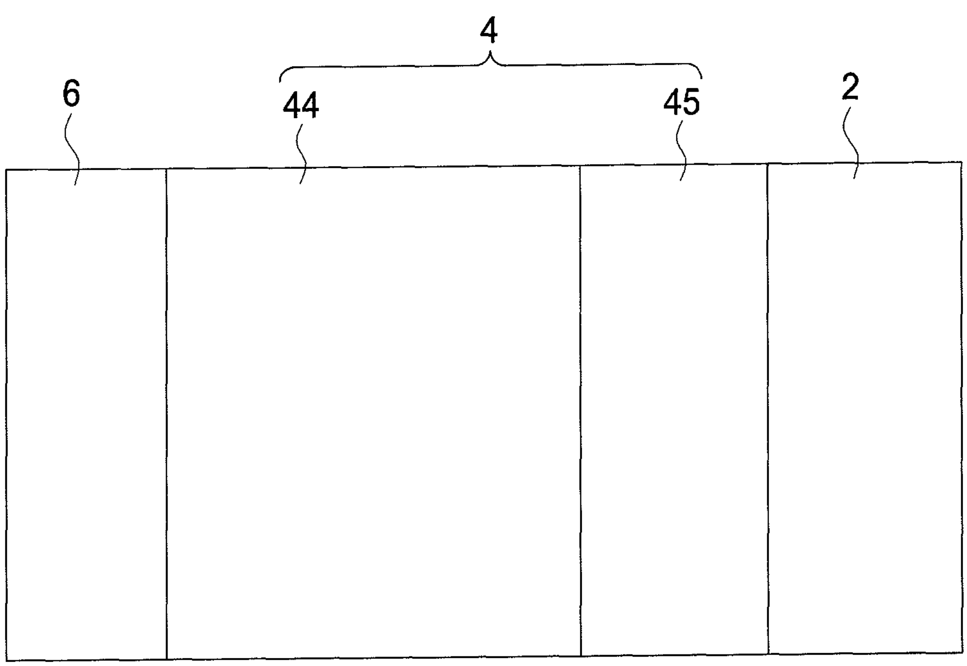


FIG.2

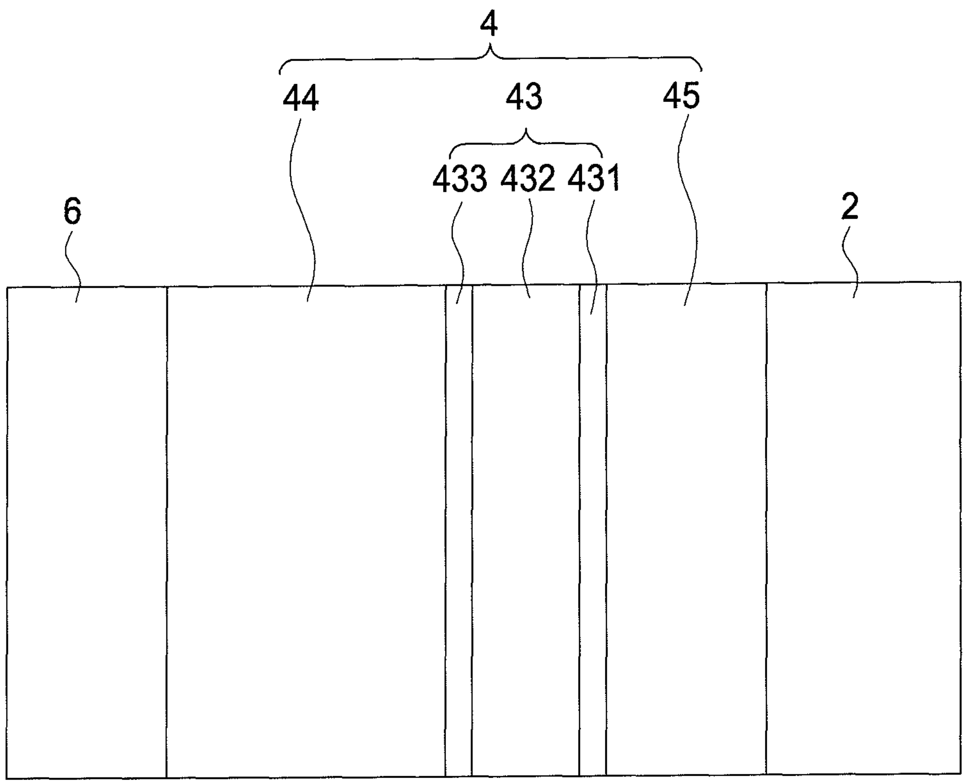


FIG.3

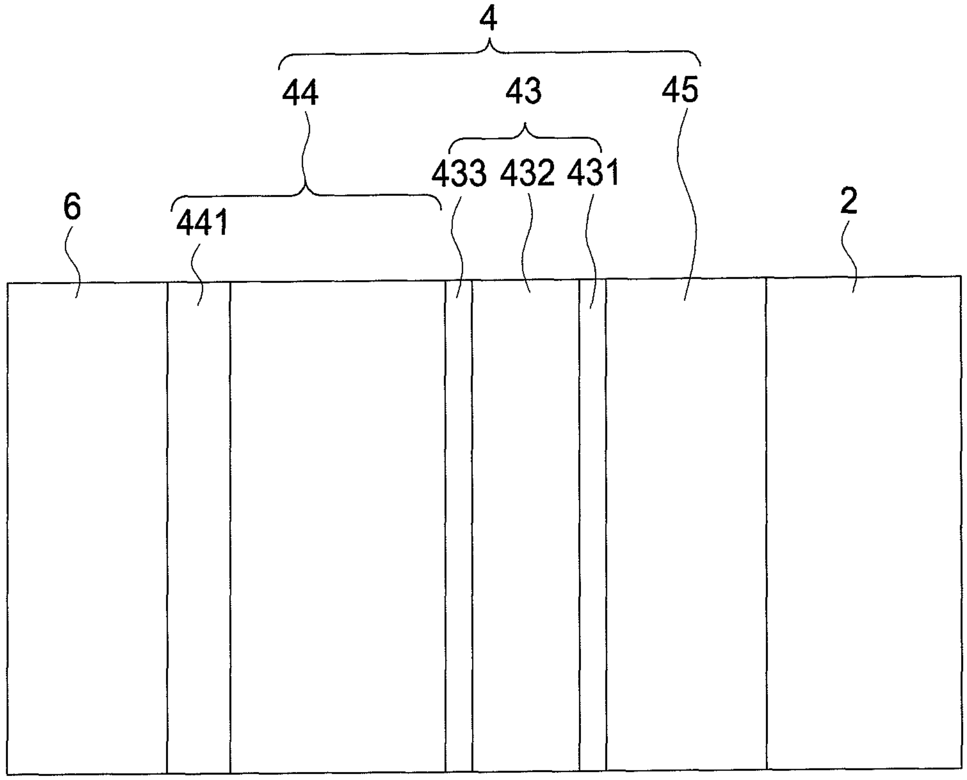

4
44
43
45
433 432 431
6
441
2

FIG.4A

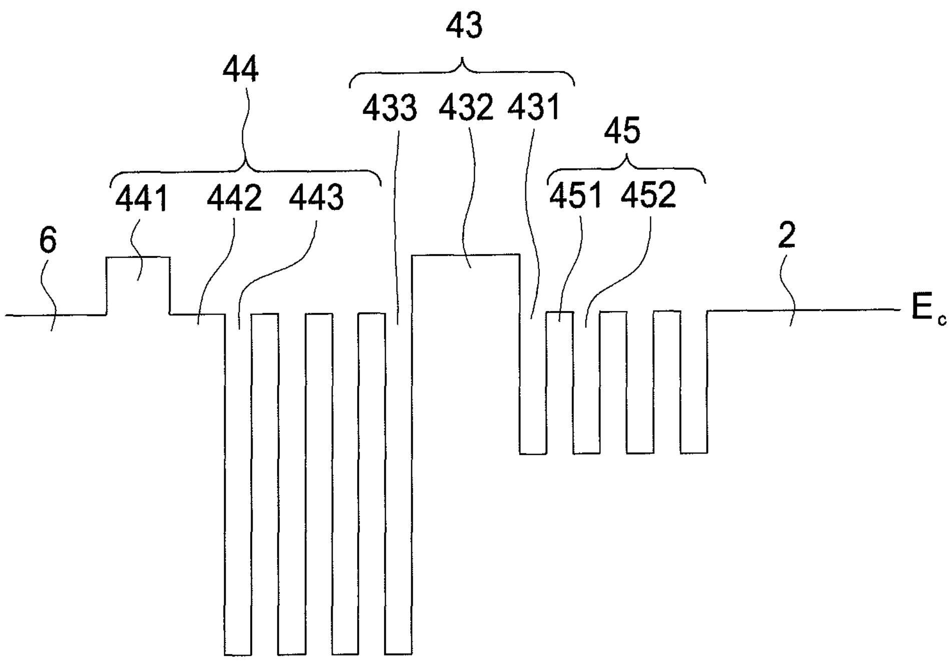

43
44
433 432 431
45
441 442 443
451 452
6
2
E_c

FIG.4B

LIGHT EMITTING DEVICE

TECHNICAL FIELD

The present application relates to a light-emitting device with an improved structure to improve the active layer performance.

DESCRIPTION OF BACKGROUND ART

As the light-emitting efficiency is increased and the cost of manufacturing is decreased, the dream for solid lighting device to replace the traditional lighting device may come true in recent years. Generally speaking, white light is provided by using blue light emitted from a light-emitting diode (LED) formed by a nitride semiconductor to excite the yellow phosphor. A nitride semiconductor including nitrogen (N) is a prime candidate to make a short-wave light-emitting device because its band-gap is sufficiently wide. Among other things, GaN-based compound semiconductors have been researched and developed particularly extensively. As a result, blue LEDs, green LEDs, and semiconductor laser diodes made of GaN-based semiconductors have already been used in actual products.

FIG. **1** shows the structure of the conventional nitride semiconductor LED **1**. The conventional nitride semiconductor LED **1** comprises an n-type semiconductor **2**, a multiple quantum well structure **4** and a p-type semiconductor layer **6**. Usually, the n-type semiconductor **2** is an n-type GaN, and the p-type semiconductor layer **6** is a p-type GaN. In order to raise the light-emitting efficiency of the nitride semiconductor LED **1**, the multiple quantum well structure **4** of the nitride semiconductor LED comprises a plurality of barrier layers **41** and well layers **42** different from the barrier layers **41**. The plurality of the barrier layers **41** and the well layers **42** are alternately stacked with each other to form the traps to capture the electrons and holes to increase the combination efficiency thereof. Generally, the plurality of the barrier layers **41** comprises Ga and N, and preferably is GaN. The plurality of the well layers **42** comprises In, Ga, and N, and preferably is InGaN. Nevertheless, the lattice constant of the GaN does not match the lattice constant of the InGaN so forms the strain in the multiple quantum well structure **4**. The strain causes the defects in the multiple quantum well structure **4** and decreases the light-emitting efficiency.

SUMMARY OF THE DISCLOSURE

A light-emitting device comprises a first type semiconductor layer, a multi-quantum well structure on the first type semiconductor layer, and a second type semiconductor layer on the multi-quantum well structure, wherein the multi-quantum well structure comprises a first portion near the first type semiconductor layer, a second portion near the second type semiconductor layer, and a strain releasing layer between the first portion and the second portion and comprising a first layer including Indium, a second layer including Aluminum on the first layer, and a third layer including Indium on the second layer, wherein the Indium concentration of the third layer is higher than that of the first layer.

A method of manufacturing a light-emitting device comprising the steps of, providing a substrate, forming a first type semiconductor layer on the substrate, forming a first portion on the first type semiconductor layer at a first temperature T1, forming a strain releasing layer on the first type semiconductor layer, forming a second portion on the strain releasing layer at a second temperature T2, and forming a second type semiconductor layer on the multi-quantum well structure, wherein T1>T2.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows the structure of the conventional nitride semiconductor LED;

FIG. **2** shows the light-emitting diode structure according to the first embodiment of the present application;

FIG. **3** shows the light-emitting diode structure according to the second embodiment of the present application;

FIG. **4**A shows the light-emitting diode structure according to the third embodiment of the present application;

FIG. **4**B shows the energy level of the conductive band (E_c) of the light-emitting diode structure according to the third embodiment of the present application.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Exemplary embodiments of the present application will be described in detail with reference to the accompanying drawings hereafter. The following embodiments are given by way of illustration to help those skilled in the art fully understand the spirit of the present application. Hence, it should be noted that the present application is not limited to the embodiments herein and can be realized by various forms. Further, the drawings are not precise scale and components may be exaggerated in view of width, height, length, etc. Herein, the similar or identical reference numerals will denote the similar or identical components throughout the drawings.

First Embodiment

As FIG. **2** shows, the light-emitting diode structure comprises an n-type semiconductor layer **2**, a p-type semiconductor layer **6**, and a multiple quantum well structure **4** between the n-type semiconductor layer **2** and the p-type semiconductor layer **6**. The material of the n-type semiconductor layer **2**, the multiple quantum well structure **4**, and the p-type semiconductor layer **6** can be the compounds which at least include nitride. In order to reduce the defects in the multiple quantum well structure **4**, the multiple quantum well structure **4** is divided into the first portion **45** and the second portion **44**. The first portion **45** comprises a plurality of the first barrier layers and the first well layers different from the first barrier layers. The plurality of the first barrier layers and the first well layers are alternately stacked with each other. The plurality of the first barrier layers comprises Ga and N, and preferably comprises Ga_xN, 0<x<1. The plurality of the first well layers comprises In, Ga, and N, and preferably comprises $In_zGa_{1-z}N$, 0<z<1. The second portion **44** comprises a plurality of the second barrier layers and the second well layers different from the second barrier layers. The plurality of the second barrier layers and the second well layers are alternately stacked with each other. The plurality of the second barrier layers comprises Ga and N, and preferably comprises Ga_xN, 0<x<1. The plurality of the second well layers comprises In, Ga, and N, and preferably comprises $In_yGa_{1-y}N$, z<y<1.

In the first embodiment, the first portion **45** is formed in a higher temperature than the second portion **44**. Thus, the first portion **45** can be called as HT-MQW (high temperature multiple quantum well), and the second portion **44** can be called as LT-MQW (low temperature multiple quantum well). The second portion **44**, which comprises higher Indium (In) concentration, is used for the main light-emitting structure of the multiple quantum well structure **4**. The first portion **45**, which comprises lower Indium (In) concentration, can be a super lattice structure to release the strain which has be accumulated in the n-type semiconductor layer **2** and decrease the strain occurred in the second portion **44**. Since the strain can cause the defects occurring during the process of forming the second portion **44**, the defects in second portion **44** can be decreased. Because the first portion **45** is formed in higher temperature than the second portion **44**, the epitaxial quality of the first portion **45** is better than that of the second portion **44**. Thus, the first portion **45** can prevent the defects which occur in the semiconductor layer **2** from spreading to the second portion **44** to reduce the number of defects thereof.

Second Embodiment

FIG. **3** shows the light-emitting diode structure according to the second embodiment of the present application. The light-emitting diode structure comprises an n-type semiconductor layer **2**, a p-type semiconductor layer **6**, and a multiple quantum well structure **4** between the n-type semiconductor layer **2** and the p-type semiconductor layer **6**. The material of the n-type semiconductor layer **2**, the multiple quantum well structure **4**, and the p-type semiconductor layer **6** can be the compounds which at least include nitride. The difference between the second embodiment and the first embodiment is that the multiple quantum well structure **4** comprises the first portion **45**, the second portion **44**, and a strain releasing layer **43** between the first portion **45** and the second portion **44**. The strain releasing layer **43** comprises the first layer **431**, the second layer **432**, and the third layer **433**. The first layer **431** and the third layer **433** are both the compounds of In, Ga, and N. The second layer **432** is the compound of Al, Ga, and N. The concentration of In of the first layer **431** is smaller than that of the third layer **433**. The concentration of Al of the second layer **432** is between 0.08 and 0.15. The thickness of the second layer **432** is between 100 Å and 300 Å. The second layer **432** is thicker than the first barrier layer of the first portion **45** and the second barrier layer of the second portion **44**. In another embodiment, the second layer **432** can be doped with Si or P to become an n-type compound.

According to a general research, the hetero junction of the compound of Al, Ga and N, and the compound of In, Ga and N can compensate the strain, wherein the strain is caused from the lattice mismatch of GaN and InGaN. Thus, the two hetero junctions, which are the first layer **431** and the second layer **432**, and the second layer **432** and the third layer **433**, can compensate the strain in the second portion **44** and meanwhile decrease the defects in the second portion **44** to increase the light-emitting efficiency.

In addition, the process of manufacturing the multiple quantum well structure **4** comprises the steps of forming the first portion **45** first, then forming the strain releasing layer **43**, and finally forming the second portion **44**. The forming temperature of the first portion **45** is near to that of the second layer **432**. Thus, during the process of forming the second layer **432**, the first portion **45** is not damaged. After the strain releasing layer **43** are formed, the second portion **44** can be formed in lower temperature to prevent the plurality of the second barrier layers and the second well layers of the second portion **44** from being damaged.

Because the defects in the second portion **44** can be reduced, the light-emitting efficiency of the multiple quantum well structure **4** can be improved and the forward voltage of the light-emitting diode can also be improved. And, on the other hand, the light-emitting efficiency of the multiple quantum well structure **4** can be more average in low and high temperature environments, which can improve the droop effect.

Third Embodiment

FIG. **4**A shows the light-emitting diode structure according to the third embodiment of the present application. The difference between the third embodiment and the second embodiment is that the second portion **44** comprises an electron block layer **441** adjacent to the p-type semiconductor layer **6**, and the electron block layer **441** can preferably be connected with the p-type semiconductor layer **6** and the second barrier layer of the second portion **44**. The electron block layer **441** is the compound of Aluminum, gallium and nitride, and can be doped with Mg or Be to form a p-type compound.

The concentration of Aluminum of the electron block layer **441** is between 0.08 and 0.15. The energy level of the conductive band (E_c) of the light-emitting diode structure is shown in FIG. **4**B. The energy level of conductive band (E_c) of the first barrier layer **451** is higher than the energy level of conductive band (E_c) of the first well layer **452**. The energy level of conductive band (E_c) of the second barrier layer **442** is higher than the energy level of conductive band (E_c) of the second well layer **443**. And, because the Indium (In) concentration of the first well layer is lower than that of the second well layer, the energy levels of conductive band (E_c) of the second well layers **443** are lower than that of the first well layers **452**.

The energy levels of the conductive band (E_c) of the electron block layer **441** and the second layer **432** are higher than that of other portions of the light-emitting diode structure. The electron block layer **441** and the second layer **432** can form the obstruction for the electronics flowing from the n-type semiconductor layer **2** to the p-type semiconductor layer **6**. Thus, the electron block layer **441** and the second layer **432** can improve the recombination percentage of the electrics from the n-type semiconductor layer **2** and the electrons respectively from the p-type semiconductor layer **6**. When the recombination percentage of the electrics and the electrons is improved, the light-emitting efficiency of the multiple quantum well structure **4** can be improved.

What is claimed is:

1. A light-emitting device, comprising:

a first type semiconductor layer;

a multi-quantum well structure on the first type semiconductor layer; and

a second type semiconductor layer on the multi-quantum well structure,

wherein the multi-quantum well structure comprises a first portion near the first type semiconductor layer, a second portion near the second type semiconductor layer, and a strain releasing layer between the first portion and the second portion and comprising a first layer including Indium, a second layer including Aluminum on the first layer, and a third layer including Indium on the second layer, wherein the Indium concentration of the third layer is higher than that of the first layer,

wherein the first portion comprises a plurality of first well layers and a plurality of first barrier layers alternately stacked, and the second portion comprises a plurality of second well layers and a plurality of second barrier layers alternately stacked, and

wherein the energy level of the conduction band of the second layer is higher than that of the plurality of first well layers, the plurality of first barrier layers, the plurality of second well layers, and the plurality of second barrier layers.

2. A light-emitting device according to claim **1**, wherein the second layer comprises Si or P.

3. A light-emitting device according to claim **1**, wherein a thickness of the second layer is between 100 Å and 300 Å.

4. A light-emitting device according to claim **1**, wherein the plurality of first well layers comprises Indium.

5. A light-emitting device according to claim **1**, wherein the second layer is thicker than each of the plurality of first barrier layers.

6. A light-emitting device according to claim **4**, wherein the plurality of second well layers comprises Indium.

7. A light-emitting device according to claim **6**, wherein the first type semiconductor layer comprises an n-type semiconductor layer, the second type semiconductor layer comprises a p-type semiconductor layer, and the Indium concentration of the plurality of second well layers is higher than that of the plurality of first well layers.

8. A light-emitting device according to claim **1**, wherein the second portion further comprises an electron block layer near the second type semiconductor layer.

9. A light-emitting device according to claim **8**, wherein the electron block layer comprises Aluminum.

10. A light-emitting device according to claim **9**, wherein the energy level of the conduction band of electron block layer is higher than that of the plurality of first well layers, the plurality of first barrier layers, the plurality of second well layers, and the plurality of second barrier layers.

11. A light-emitting device according to claim **8**, wherein the electron block layer is doped with Mg or Be.

12. A light-emitting device according to claim **8**, wherein the energy level of the conduction band of the electron block layer is higher than that of the plurality of second well layers and the plurality of second barrier layers.

13. A light-emitting device according to claim **1**, wherein the second portion emits a blue light.

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